DOCUMENT RESUME

ED 134 342 PS 009 081

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TITLE Effects of an Elementary Strategy on Operations of Exclusion.
PUB DATE Nov 76
NOTE 28p.; Paper presented at the Annual Convention of the American Psychological Association (84th, Washington, D.C., September 3-7, 1976)

EDRS PRICE MF-$0.83 HC-$2.06 Plus Postage.
DESCRIPTORS *Age Differences; *Cognitive Development; *Elementary Education; Elementary School Students; *Problem Solving; Research Methodology; *Thought Processes; Transfer of Training
IDENTIFIERS Piaget (Jean)

ABSTRACT

Effects of an advance organizer lesson (containing high-order science concepts relating to the law of capillary attraction, and an elementary problem-solving strategy for determining causal relations) were evaluated for a sample of 80 urban 6- and 10-year-old children. Significant sequential transfer effects were established from the lesson. Improved performance for experimental groups was maintained on a retention test and transferred to a second problem in that class of problems involving operations of exclusion. There was a marked tendency for performance to improve with age. Results suggest that acceptable solutions to problems requiring the operations of exclusion may be achieved without the use of complex propositional logic. (Author/MS)

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ED134342

Effects of an Elementary Strategy on Operations of Exclusion

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PS 009081

November, 1976

Abstract

Effects of an advance organizer lesson, containing high-order concepts relating to the law of capillary attraction, and an elementary problem solving strategy for determining causal relations, were evaluated for a sample of 80 urban six and ten-year-old children. Significant sequential transfer effects were established from the AO lesson. Improved performance for E groups was maintained on a retention test and transferred to a second problem in that class of problems involving operations of exclusion. There was a marked tendency for performance to improve with age. The results suggest that acceptable solutions to problems requiring the operations of exclusion may be achieved without the use of complex propositional logic.

Effects of an Elementary Strategy on Operations of Exclusion

The purpose of this study was to investigate the effects of an advance organizer lesson, presenting high-order science concepts and an elementary problem solving strategy for determining causal relations (adapted from Ausubel & Robinson: 163), on children's use of operations of exclusion (as defined by Inhelder and Piaget, 17: 67-79).

The use of operations of exclusion are exemplified in the "Pendulum Problem". In this type of experiment Piaget maintains that the child must understand why the multiple variation of possible causal factors leads to ambiguous categorization. The child must rather spontaneously vary each factor in turn whilst holding the remainder constant. Only then is it possible to identify the relevant variable. Piaget has termed this type of thinking "formal operations".

Inhelder and Piaget (17) maintain that the critical distinction between formal reasoning and reasoning in young children is the hypothetico-deductive nature of the former. The onset of formal reasoning is said, by Piaget, to begin at about 11/12 years of age and reaches its full realization at about 14/15 years. A more recent Genevan interpretation would place the onset of formal reasoning at a later age than 14/15 years in certain circumstance. Piaget also suggests, for some individuals such thinking may only occur in a field of specialization. Concrete operational thought, according to Piaget, deals with the direct organization of perceptual or imageable data. Though the child, at this stage of development, can extend the actual in the direction of the possible, he cannot yet imagine the effect or reality of fulfilling hypothetical conditions. At the formal level of

thought, series of hypotheses can be elaborated, consequences deduced, and hypotheses selected compatible with evidence resulting from or applicable to experimentation.

In comparison to the vast amount of research addressed to the area of concrete operations little research has been directed toward Piaget's contention that logical thought, as reflected in the use of propositional logic, becomes possible only in pre-adolescence.

Follow up studies, for example, Lovell (25), Jackson (18), Hughes (16), Davis (11), using the same general types of experiments as those used by Inhelder and Piaget (17) support the trends in stage development found by the Genevan Studies. Other studies, Ervin (12), Lodwick (24), Case and Collinson (9), also support the Genevan position. However, age of onset of formal thought has been found to vary according to the complexity of the task and the pupil's familiarity with first order relations which underpin the task.

It would appear that Piaget's stage of formal operational thinking has a more limited application than was once considered to be the case. Research has shown that experiments requiring the manipulation of variables and those involving direct and inverse proportion tend to cluster, suggesting less structure than is implied by Piaget's description of formal operations. Lunzer (27) states there is little support for a prior assertion that advances in thinking are a function of advances in logic. Wason and Johnson-Laird (31) criticize assumptions regarding the use of the propositional calculus. For example, they contend that the nature of the 'content' of a problem plays a vital role in formal thinking.

Ausubel presents an interesting view of problem solving. He states that, "undoubtedly the most sought after kind of transfer

(vertical) is that in which the learner uses previously acquired concepts and generalizations in the process of problem solving". (Ausubel & Robinson, 7: 157). He proposes that, for problems such as the pendulum problem (i.e. operations of exclusion) young children (between ages 6-11 years) require considerable instruction. He acknowledges Piaget's warning, that children in this age group tend to vary two independent variables at once, and thus become confused. In order to circumvent this type of error, Ausubel suggests that the proposition the child needs to know, one independent variable at a time must be manipulated, and its effect on the dependent variable observed, can be made meaningful to children of this age. Three things are necessary: 1) Provide an "elementary strategy" (e.g. Ausubel & Robinson, 7: 163) for determining causal relationships. This strategy would be presented as high-order rules for manipulating variables; 2) Provide all necessary concrete exemplars of the concept "variable" (dependent, independent) and demonstrate the rules in some way; and 3) Make it clear to the child that the elementary strategy can be applied to a class of related problems.

From this perspective, teaching for problem solving is concerned with a number of issues. First, problems must be related to the developmental stage of the problem solvers. Second, different types of problems probably require different styles of thinking to effect a solution. Third, no single set of principles of instruction for problem solving can be drawn from present theory or the results of research.

The teaching of elementary strategies advocated by Ausubel is a variation of his basic concept of the process involved in meaningful learning and retention. The teaching strategy to be used is expository and the learning initially receptive by way of advance organizer lessons.

"Advance organizers are introduced in advance of the learning material itself and also are presented at a higher level of abstraction, generality and inclusiveness". (Ausubel & Robinson, & 7: 165). These lessons are contrasted with introductory lessons which present information at the same level of abstraction as subsequent materials, emphasizing key concepts and facts, and achieving their effect mainly by repetition and simplification.

Initial studies relating to the subsumption theory of learning, for example, Ausubel (1) and (2), Ausubel and Fitzgerald (4), Ausubel, Stager and Gaite (5) and (6) and a number of secondary studies, for example, Gagne (13), Gagne and Weigand (14), Kass (19), support the contention that 'advance organizers' do facilitate meaningful learning and retention. It must be noted, though, that other studies, for example, Livingston (23), Barron (8), Lucas (26), and Clawson & Barnes (10) have found little or no support for the theory. Highly structured content has been shown to lead to more meaningful learning, for example, Guetzkow, Kelly and McKeachie (15), and Ward (29). Studies by Scandura and Wells (28), and Kuhn and Novak (21), and (22), support the enhancing effect of prior organizers on the acquisition and retention of learning materials in a 'science' context. However, although there is evidence which supports this process of learning, there is little evidence from classroom teaching procedures.

Ausubel and Robinson (7: 259) claim that, as long as the young child has direct non-verbal contact with learning materials, derivative verbal concepts and propositions may be meaningfully understood when presented rather than discovered. Although the investigator concurs with Piaget's statement that childish reasoning will be less deductive and rigorous than

that of the adult, it can be expected, from Ausubel's point of view, that prior knowledge of concrete exemplars of variables in a problem, along with an elementary strategy for manipulating variables, will have an important effect on the child's use of "if-then" thinking. It is predicted that such knowledge can be acquired by young children via expository teaching, and later implemented in problem solving tasks.

Problem

It was predicted that an advance organizer, presenting high-level subject matter concepts related to capillary attraction and high-level rules as an elementary strategy for determining causal relationships would facilitate both children's learning and retention of meaningful verbal materials and their ability to resolve problems dealing with operations of exclusion. It was further predicted that the elementary strategy would facilitate transfer of learning to a second, related problem.

Two related problems were constructed according to Piaget's description of problems involving operations of exclusion (Inhelder & Piaget, 7: 67-79) for investigating children's use of "if-then" thinking in this type of problem. The first problem dealt with the law of capillary attraction and the second with the pendulum problem (i.e. the law of rate-of-swing of a pendulum).

Method

Subjects

Subjects were 80 children selected at random in each of the age groups 6-1/2 to 7 years (mean CA = 82 months; range = 79-84 months) and 10-11 years (mean CA = 128 months) from two elementary schools in an urban area, so that each group was comprised of 40 children (in each case, 20 children from each of the two schools).

Each six-year-old child was individually tested on the English Picture Vocabulary Test-I. (mean score = 108; S.D. = 6·8). The ten-year-old children received a group administered EPVT Test-II. (mean score = 112; S.D. = 5·4).

For each age-group, in each school, the respective groups of 20 children were randomly placed in one experimental group and one control group. The differences between group VR test means for each age-group and between age-groups by school were not significant. Thus, treatment groups in all cases were initially comparable by VR score. Also, the two age groups, compiled from two schools could be treated as homogeneous.

Materials

Instructional materials consisted of an advance organizer lesson (AO) and an introductory lesson (IL).

The AO lesson was constructed by firstly completing a content analysis of chapter 4 in Inhelder and Piaget (17) to establish the rules for operations of exclusion. Reference was also made to Ausubel and Robinson (7: 163) in order to identify a number of sequential high-order rules in an elementary strategy for the solution of problems involving the operations of exclusion. The high-order rules established were as follows: 1. identify and name independent variable; 2. list and order (eg. classify, serial order) independent variables; 3. concentrate on the first independent variable - make it take different values while changing nothing else; 4. summarize results of (3) in form of verbal statement; 5. take next independent variable and repeat (3) and (4) - and so on through all independent variables; 6. summarize overall results in a verbal statement.

Secondly, references to capillary attraction were similarly analyzed

and high-order concepts regarding the law of capillary attraction constructed. Both high-order subject matter concepts and high-order rules for problem solving were incorporated into the AO lesson.

The problem-solving strategy was taught by way of a 'game'. The apparatus for the 'game' is shown in Figure 1.

Insert Figure 1 about here

The game consists of moving three, colored wooden blocks, varying from thin through medium thin/wide to wide, on a matrix board (Figure 1). Below the matrix-spaces (numbered 1-3 for each column) 'starting position' spaces were placed, and below each 'starting position' three 'pretend' button-switches were painted in numbered 1-3. The children are told there is a rule to the game they have to find. The rule allows that only ONE of the three wooden blocks will go farthest up each vertical line of 'spaces' on the matrix. It is demonstrated that the wooden blocks can be placed on the 'starting positions' and the 'pretend' buttons can be pushed. When this occurs, the block(s) may or may not move upwards on the spaces above the 'starting positions'. They are also told that the experimenter knows the rule and will move the blocks according to the rule as the game is played. (The rule can be varied so that the game may be played a number of times. However, changing of the rule does not effect the manner in which critical moves must be made. eg. The wider the block the higher up the matrix spaces it will move when button-switch 1 is pressed; or, the narrower the block the higher it will move up the matrix spaces when button-switch 3 is pressed). The main emphasis in the game was to instruct children to order data (eg. serially ordered

blocks is an economical way to organize data before beginning moves), to vary each block in turn, to take each block through the same sequence of moves, and to adopt the same sequence of moves (eg. order of 'starting position', order of pushing'pretend' button-switches etc.) for each block which would most likely guarantee a correct solution to this type of problem. Klausmeier (20: 58) says, '...concept learning is facilitated if information concerning relevant attributes and/or the appropriate rule structure of the concept is given to the learner at the outset, particularly if the attributes are not obvious, and if the rule structure is complex.'

Control groups received an 'introductory lesson' presenting detailed information on the law of capillary attraction. Both the AO lesson and the IL took about 50 minutes to teach.

Apparatus for the Experiment

The apparatus used for the first problem consisted of the following items: 1. five capillary tubes with differing dimensions of bore; 2. a board measuring 10" x 8" painted white and supported in a vertical position on a base board. (The lower part of the upright board was marked with black, equal interval, horizontal lines intended to serve as an aid for estimating height of liquid in capillary tubes. Five clips, placed equi-distant apart, were screwed into the board and were intended to hold the five capillary tubes. Five black circles were painted onto the base-board so that their positions coincided with the positions of capillary tubes) 3. three liquids of differing density from thick through thin to very thin (for the pre-test these liquids were colored light-green, red and dark green, and for the post-test red, dark green and light green respectively) 4. fifteen clear perspex dishes (for the pre-test each of

the three liquids was placed by equal amounts into five dishes in each case. For the post-test the three liquids were placed by approximately equally increasing amounts into each of five dishes in each case from a dish containing the least amount to one containing the greatest amount. For the pre-test, these dishes might be classified by type of liquid. For the post-test, the dishes might be serially ordered by amount of liquid and classified by type of liquid in a 3 x 5 matrix).

The capillary attraction experiment was constructed to provide a similar problem to Piaget's, 'The Oscillation of a Pendulum and the Operations of Exclusion' (Inhelder and Piaget, 17:67-79). For the pre-test, the variables the child might think were relevant are; diameter of bore of capillary tube; density of liquid; and depth to which a tube might be placed in the liquid (for the post-test, a fourth variable was added; amount of liquid). For both pre- and post-test only the first variable is relevant: that is, the degree of capillary attraction varies according to the diameter of bore of the capillary tube; the narrower the tube the higher liquid ascends due to capillary attraction within the tube. The problem, as in the pendulum problem, is to isolate the relevant variable and exclude the remainder.

Apparatus for the second problem consisted of a metal stand about 2 feet high with a cross-piece from which was suspended a string. Attached to the end of the string was a holder for disc-weights. The string could be lengthened or shortened as desired. Three different weights were used made up from disc-weights (the term 'weight' is used when strictly the term 'mass' should be used, since the term weight is more familiar to the child and does not adversely effect the course of problem solving). The child was shown how the pendulum could be

constructed and set in oscillation in various ways. The task was to discover which variable governs the frequency of oscillation of the pendulum. (Only the length of the pendulum affects the period of oscillation. Other variables which might be thought to affect the period of oscillation are weight, height of drop of pendulum, velocity of push of pendulum).

These materials are basically the same as those used by Piaget for the original pendulum problem.

Validity

Content Validity of Two Problems

Both problems were constructed in accord with Piaget's description of problems involving operation of exclusion. The description of the AO lesson and IL were presented to three judges who were asked to a) check the accuracy of the scientific concepts and b) indicate any differences they perceived in the form of the two lessons. A similar judging procedure was carried out with respect to the problem protocols to ensure replicability of Piaget's protocol for administering the original pendulum problem. The results from this process confirmed the accuracy of the scientic concepts, discriminability between the two types of lessons and comparability of the two problem protocols with the procedure for administering the pendum problem used by Piaget.

Reliability

From data obtained in a pilot-study of this experiment a coefficient of task reliability was computed using the Kuder-Richardson formula 20 which yielded an r of .78.

Procedure

Testing

For both problems, each child was tested individually on both pre- and post-tests.

Prior to the first problem it was explained to the child how size of bore of tube, type and density of liquid and depth of tube in liquid might be varied. A method for estimating height of liquid in a tube was explained and, at the same time, the child was told that liquids 'like to climb up the inside of hollow tubes'. The child was asked to describe reasons for any manipulation of the apparatus he might choose to make and to say what he noticed as he proceeded with the experiment. As each child's experimenting proceeded a number of questions were asked. First, E asked the child to predict the outcomes of any of his actions. Second, questions were asked of the child so that a completed move or series of moves might be described. Finally, a solution was only judged correct when adequate causal explanation and logical justification was forthcoming. In the case of the second problem it was demonstrated to the child that a pendulum swings back and forth. It was explained how period of oscillation, weight on the pendulum, height of drop of pendulum, velocity of push of pendulum and length of string of the pendulum might be varied. A method for measuring "rate of swing" was indicated by the experimenter, using a metronome.

Scoring Procedure

Children's responses were tape-recorded and transcripts subsequently made. The transcripts were scored either 1, 2, or 3 according to the scale used by Piaget (Inhelder and Piaget, 17) indicating the "stage-quality" of response. Scoring of protocols was completed by two independent scorers. (Inter-scorer reliability, $r = .82$).

A score of 1 indicates that child is operating at the pre-operational level-i.e. variables are not clearly identified, more than one variable is manipulated at one time and no clear-cut solution is achieved; a score of 2 indicates that a solution is achieved by a great deal of trial and error procedure and with assistance from the E; a score of 3 indicates a correct solution with no assistance from the E and with the child proceeding straight forwardly and carefully, identifying relevant variables and applying a correct strategy for obtaining a solution.

It is important to point out to the reader that a correct solution, receiving a score of 3, does not indicate the use of the complex system of hypothetico-deductive reasoning as described by Piaget. In this type of problem, where the variables can be concretely identified and manipulated, concrete-operations such as classification (e.g. classification of liquids) and seriation (e.g. seriation of capillary-tubes, or liquid by amount) are necessary. But they, along with the elementary problem-solving strategy, are all that is required to achieve a solution.

Teaching Schedule

Following the pre-test of problem 1 (the capillary-attraction problem) the AO lesson and IL were taught on a group basis (5 children in each group). Each lesson took about 50 minutes to complete.

Results

Problem 1

Each child's protocol was assessed overall and classified in one of the three categories referred to above. This data is presented in Table 1. In the case of this data, as for all subsequent data, chi-square values were computed for the various comparisons.

Insert Table 1 about here

Pre-test data indicates that the capillary attraction problem was apparently a most difficult problem for these children. Although rather more older than younger children achieved scores above the stage 1 level, this is not a significant difference. Comparisons between treatment groups also indicated no significant differences in performance.

Children's protocols and observed problem solving behavior suggest that both naivety as regards the task content coupled with the complexity of the task affected performance to a considerable degree.

Following post-testing, comparisons were made between data from the two treatment groups in each age-group, and between age-groups. First, experiment groups significantly improve performance over that of control groups: 6-E v 6-C, $X^2 = 16{\cdot}95$, df = 1, $p < .01$; 10-E v 10-C; $X^2 = 9{\cdot}60$, df = 4, $p < .05$. These data support a facilitating effect from the AO lesson. Second, performance did appear to improve as a function of age: 10-E v 6-E; $X^2 = 11{\cdot}39$, df = 4, $p < .05$; 10-C v 6-C, $X^2 = 14{\cdot}74$, df = 1, $p < .01$. This result not only supports Piaget's contention, that problem solving behavior can be expected to improve as a function of age, but also that content and problem solving strategy naivety very likely affected pre-test performance as previously noted, especially for the older children. Finally, performance of E groups, especially in the case of younger children, does support Ausubel's hypothesis that, providing the variables in a problem can be concretely identified and the child provided with an elementary strategy for manipulating variables to a solution, it can be expected young children in this age-bracket can deal adequately with certain types of "if-then" thinking.

Six weeks after completion of the post-testing for problem 1 the capillary-attraction problem was re-administered to test for retention. Data from the repeat testing is presented in Table 2. Scores in the

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Insert Table 2 about here

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adjoining cells for stage 2 and 3 of the 3-stage scale were combined, thus producing fourfold tables of frequencies. The McNemar Test was then used to test for significance of change between the post-test performance of problem 1 and that on the repeat testing. (see, for example, Siegel 29: 63). It was established that no significant changes occured in children's performance generally. This data supports the expectation that the AO lesson would also facilitate retention of information learned by this procedure.

Problem 2

Finally, immediately following the repeat testing of the capillary-attraction problem, the pendulum-problem was administered. Data from the pendulum-problem task is presented in Table 3. Comparison of data

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Insert Table 3 about here

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from the pendulum problem and capillary attraction tasks indicated no significant changes in performance.

Thus, these data support 1) durability of learning from the AO lesson, and 2) sequential transfer of an elementary strategy to a second problem in a general class of problems, all of which require the identification of a single independent variable affecting the phenomenon in question, and the exclusion of all other variables.

Conclusions

The results reported here support the prediction that the AO lesson would facilitate the solving of problems in a general category of problems involving operations of exclusion. The post-test performance of six-year-old E group children was at a level beyond that expected for this age group according to a strict interpretation of Piaget's stage theory. However, improved performance is interpreted here, for both age-groups, moreso as a move to a more advanced level of problem solving. The problem solving performance of ten-year-old E group children was demonstrably of a higher quality than that of their younger counterparts. For example, having serially ordered liquid by amount some of the older children tested least and greatest amounts interpolating results of testing to intermediate amounts in the sequence. They also, more surely separated out variables, constructed serial ordering, and stated correct correspondence using a higher quality of verbal expression.

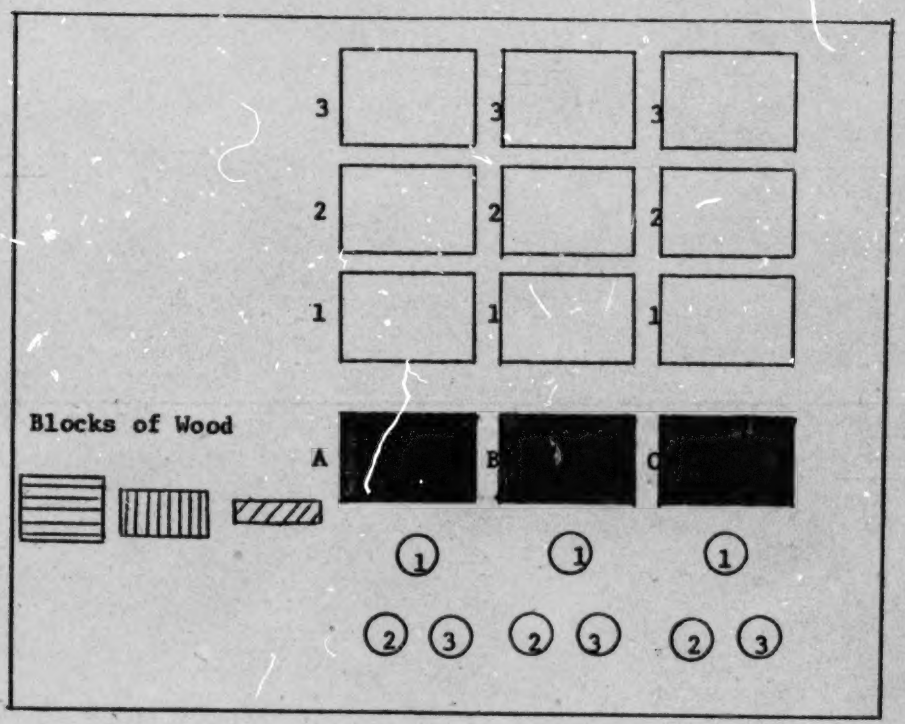
It is not argued, from these results, that success is evidence of formal operational thinking. Although E group children's problem solving displayed many features of formal thought, with respect to operations of exclusion, its main import lies in the organization of concrete data. Ausubel (3) emphasizes the importance of sequence in the pedagogic facilitation of transfer. It can be expected young children will be able to solve related problems, such as those reported here, when using elementary strategies such as that taught in the AO lesson as long as the variables being manipulated can be concretely exemplified.

For Piaget, the critical determinant of formal thinking (hypothetico-deductive reasoning) is the equilibration of group-lattice structures, which is supposed to occur after age 12 years. In Ausubel's view the

child may arrive at a useful and generalizable solution to certain types of problems without using a detailed combinational form of reasoning. He suggests that the critical question for the teacher should be whether the child can actually solve the problem using some suitable strategy. Piaget has been criticized for superimposing upon such problems as the pendulum-problem a conception of thinking which vastly exceeds in complexity that normally used by mature problem-solvers. Success of E group children measured by these criteria supports the contention that young children can, to a limited degree successfully engage in 'if-then' deductive reasoning. However, it must be stressed again that, in both problems reported here, children are aided by an elementary strategy containing high-order rules and the judicious use of concrete empirical props. Also, both problems involve the manipulation of concrete data, which constitutes nearly all the child requires for a solution.

Figure Caption

Figure 1. Apparatus for Teaching Operations of Exclusion



Matrix of Spaces

Starting Positions

'Pretend' Button-switches

Color Coding for Wooden Blocks

Red

Green

Blue

Table 1

Distribution of solutions to the capillary-attraction problem on the three-stage-scale

Age-treatment group	N	Pre-test 1	Pre-test 2	Pre-test 3[a]	Post-test 1	Post-test 2	Post-test 3
6 - E	20	16	4	0	7	11	2
6 - C	20	18	2	0	19	1	0
10 - E	20	12	8	0	2	6	12
10 - C	20	14	5	1	8	9	3

[a] 1, 2, & 3 can be loosely interpreted as successive 'stages', or levels of problem solving.

1 = no correct solution. The usual error is to manipulate two or more dependent variables at one time, thus confusing the single factor, in this type of problem, which is affecting the phenomenon.

2 = a correct solution with a great deal of trial and error, and some help from the E.

3 = a correct solution with very little trial and error. A positive use of an elementary strategy is used and no help is given by the E.

Table 2

Distribution of solutions to the repeat capillary-attraction problem on the three-stage-scale

Age-treatment group	N	1	2	3[a]
6 - E	20	8	11	1
6 - C	20	18	2	0
10 - E	20	0	8	12
10 - C	20	9	8	3

[a]See Footnote to Table 1

Table 3

Distribution of solutions to the pendulum-problem on the three-stage-scale

Age-treatment group	N	1	2	3[a]
6 - E	20	6	13	1
6 - C	20	14	6	0
10 - E	20	0	7	13
10 - C	20	6	11	3

[a] See Footnote to Table 1.

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